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# Off-grid solar lighting systems: A way align India's sustainable and inclusive development goals

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A B S T R A C T

Revisiting and uplifting Solar Energy sector is one of the major steps taken by India in its pursuit for sustainable development in the recent past. The present paper, though appreciates this move, makes a case for less focused tail-end solar applications: Solar Off-grid Lighting Systems (SOLS), Solar Lanterns and Solar Home Lighting Systems. Following a critical review of the policies, we present an overview of SOLS-diffusion trend in the past one and a half decades; the pattern of diffusion across states and financial assistance allotted for development and promotion of SOLS. We examine the adoption pattern at household level and factors that determine the same employing a multinomial logit model. Installation of SOLS witnessed a declining trend over the years. States exhibited considerable variation in the installation of the two SOLS and the funds allocated by the central government are not comparable to their respective energy poverty intensity. It is encouraging to note that more than half of the SOLS adopters find it an adequate source of energy. Improvement in the status and increase in the cost of alternative sources of energy adversely influence the household's choice of using SOLS as a complementary source of energy; improvement in the status of SOLS and increase in the financial strength of the household encourages them to adopt one.


**Contents**



## 1. Introduction

India placed inclusive development, ensuring a broad-based improvement in living standards of all sections of the people, as one of the development goals for the past two of its five year development

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plans [1,2]. Access to energy services have a great say in the quality of life – productivity, health, education, safe water and communication services [3]. However, India's energy consumption pattern is charecterised by a large mass of rural households depending on inadequate and poor quality energy sources (for a comprehensive review of the energy status of rural India see [4,5]). Therefore, as a major stride towards achieving inclusive development, nothing more appropriate than providing qualitative energy services to all would fit the bill. Concurrently, India put forth sustainability as its approach towards growth and development [2] i.e. meeting the needs of the present without compromising the ability of future generations to meet their own needs [6]. In this regard, Solar Energy (SE) is one of the sectors that are identified to support this endeavor. Despite the abundance,[1] SE is one of the expensive energies in terms of the generation of power and manufacturing of equipment.[2] Therefore, efforts to boost SE are indeed laudable.

Rural areas of India are situated in remote localities which retard the efforts to provide efficient network systems for supplying energy services. This is one of the primary reasons for the inability of a large section of the population to access uninterrupted quality energy services. In order to overcome this problem, studies propoganded energy services and devices that are small scale, decentralised and amenable for local control, renewable, universally accessible and affordable [7–11]. Studies also covered many region level case studies examining success, failures and prospects for small scale renewable energy applications (for example see [12–14]). Small scale decentralised green energy systems would be one of the ideal solutions for rural India to achieve inclusive development through a sustainable mode. Through the present study we intend to make a case for one of the small scale SE-Solar Off-Grid Lighting Systems (SOLS) i.e. Solar Lanterns (SLs) and Solar Home Lighting Systems (SHs) and argue for a robust development and promotion system for it to emerge as a quality efficient and economically viable source of energy parallel to electricity. In order to do so, it is vital that we have a fair understanding of the present status of SOLS in India i.e. policy design, nature of its diffusion and factors that determine their adoption. This forms the objective of the present paper. The rest of the paper is organised as follows. Firstly, we shall put forth the motive of the paper by presenting the energy scenario in rural India and a critical account of policy initiatives that fall short of creating a comprehensive environment for the development and promotion of SOLS. Secondly, trends and pattern of SOLS diffusion over time and across regions, financial assistance and usage at household level. Thirdly we undertake an econometric exercise to examine the factors that determine the adoption of SOLS by the households. Finally, we conclude the paper by presenting issues for further deliberations.

## 2. Why solar off-grid lighting systems?

According to the Household Energy Consumption Statistics published by National Sample Survey Organisation (NSSO), 2009–10, 34% of rural households depend on kerosene, candles etc for lighting. Due to substantial demand–supply gap in the production of power and anomalies in the distribution mechanism, there exists an incessant problem of blackouts and brownouts in the rural areas. According to Seventeenth Electric Power Survey of India (2007–08), 27% of the generated power is lost during transmission and distribution. 41% of the households that use electricity as primary source of energy reported that it was inadequate. Further, intensity of this inadequacy is as high as 94%.[3] Among the households that use kerosene for lighting, owing to limited quantity of kerosene accessible through Public Distribution System (PDS) and inefficiencies associated with the mechanism, more than quarter of the kerosene used is procured through non-PDS mechanism which is unsurprisingly costlier.[4] An average rural household consumes 36 liters of kerosene annually accounting to consumption of 3737 million liters and cutting on a saving of Rupees (Rs) 4336 million annually by the rural households.[5] Further, subsidising kerosene to poor households exerts pressure on the State's exchequer. For the year 2010–11 subsidy provided for kerosene under PDS accounted to Rs 93,000 million and under recovery of oil companies[6] accounted to Rs 195 billion [15]. The fumes that emerge during the combustion of kerosene give rise to health problems ranging from eye, skin and respiratory problems. Prolonged contact with kerosene combustion fumes proved to be fatal [16]. Access to energy services, unlike other tangible/intangible assets, do not accrue any economic gains to the user and thus do not uplift them from poverty. However, accessibility to minimum energy services ensures decent standard of living. Having a reliable, efficient and clean source of lighting enables smooth functioning of various activities after sunset – cooking, child care, education for children, source of lighting for cottage industries (basket weaving, match making etc). The present scenario of energy for lighting in rural India is charecterised by poor status of electricity as a modern source of energy and substantial dependence on traditional source of energy like kerosene which is not only costly but also inadequate and unhealthy.

Though SE policies in India had been critically reviewed by earlier studies (for a comprehensive review see [17]), the following review is in perspective of off-grid solar applications. Development and promotion of Renewable Energies (RE) in India lies within purview of the Ministry for New and Renewable Energy (MNRE). The aims set and functions of MNRE, before half a decade or so, is largely independent and had limited relation to the energy planning of the economy as a whole. The following are a few of the energy policies drafted in the recent times which recognised the role of REs (both small and large scale applications) but did not outline a comprehensive plan for development of SE nor road map for achieving the targets was considered. India's first ever Rural Electrification Policy of 2006, in compliance with Electricity Act, 2003, aimed to ensure access to electricity for all households by the year 2009. National Electricity Policy, 2005[7] and National Tariff Policy, 2006 stressed on Power Purchasing Agreements where state Electricity Regulatory Commissions ought to procure minimum percentage of RE power. Rajiv Gandhi Village Electrification Scheme, 2005 aimed to electrify all the villages.

[1] India, being a tropical country, has the privilege of having 301 clear sunny days in a year.

[2] The cost of power generated from coal and natural gas can range from Rs. 2 to 3 per KWh. The cost of wind power falls between Rs. 3 and 3.2 per KWh. However, the cost of Solar Power from photovoltaic cells and solar thermal falls between Rs. 10 and Rs 15 per KWh (Annual Report, Ministry of New and Renewable Energy, 2009).

[3] Intensity of inadequacy of the electricity is calculated as the ratio of the quantity of the kerosene used by the households that reported electricity as their primary source of energy for lighting to the quantity of the kerosene used by households that reported to use kerosene as primary source of energy. Here we discounted the households that use kerosene as primary source of energy for cooking.

[4] Cost of kerosene supplied at non-PDS outlets is on an average costlier than kerosene purchased at PDS outlets by 6 Rs per liter (NSSO, 2004–05).

[5] As estimated from data provided by NSSO (2004–05) data.

[6] The Oil Marketing Companies (OMC) pay trade/import parity price to refineries when they buy kerosene. The difference between the trade/import parity and the regulated selling price (excluding taxes, dealer commission) results in the under-recoveries in oil companies, the burden of which has been shared by the government (oil bonds), upstream oil companies (offer of discount on crude oil sold to the oil marketing companies) and OMCs themselves.

[7] Designed in compliance with the Electricity Act, 2003,

Further, disbursement of small scale/off-grid SE applications are considered to be a temporary arrangement and such areas are not to be declared as electrified until they are connected to a electricity distribution network. Such a biased approach offers little help to REs in general and SE in particular for them to emerge as a parallel source of energy. On the other hand, MNRE charted a variety of policies towards development of SE with respect to the manufacturing of the physical equipment or generation of energy – subsidies, soft loans, concessional duty on raw material imports, excise duty exemption on devices/systems etc. SOLS were disseminated for more than two decades through centrally subsidized programmes – Solar Lantern Programme and Solar Photovoltaic Programme.

Actively engaged in international climatic discourse, following the United Nations Framework Convention on Climate Change, India took a step forward to combat global climate change by designing the National Action Plan on Climate Change in 2008. Development and promotion of SE is one of the eight national missions charted in the plan and thus formed the Jawahar Lal Nehru Solar Mission (JNSM) with an ambitious target to generate 22 GW of SE capacity by 2022. Under this scheme, a huge subsidy was proposed for the development and promotion of SE in three phases. Though this programme is undoubtedly a leap forward, it had been criticised for being skewed towards gird connected large scale SE applications; underrating the potential of small applications, scale and method of allocation of funds [18–21]. The programme aimed to disperse 20 million SOLS by 2022.[8] Studies opined that this falls way short of 70 million households that depend on unsustainable sources of energy for lighting. Assuming that the number of SOLS diffused till 2010 is part of the JNSM target of 22 million, India would be able to achieve this target if it succeeds to diffuse 1.4 million SOLS annually. This is almost equal to cumulative number of SOLS diffused till 2010. This calls for an army of trained technicians, a fast but efficient compilation of networks of local bodies for identifying the beneficiaries and advertising the systems, financial institutions to assist the poor households and after sales service providers for a prolonged and efficient use of the systems. However, the funds allocated for this enormous task accounts for only seven percent of the total budget of the programme (see [19] for estimation of budget allocation). A review of the financing mechanism of these systems is necessary. In fact a range of studies debated about innovative methods to finance energy services to rural areas in developing countries (for example see [22,23]). The mission draft stated to focus on promoting off-grid and decentralised systems in the first phase (2010–2013) of the programme because “key opportunity of solar power lies in decentralised and off-grid applications where grid power is not available or not cost effective”. However, counter intuitively, reviewing the status of phase I of JNSM, phase II policy document stated that phase I of the mission largely concentrated on grid connected large scale SE applications. In the first two years of phase I of JNSM, an average of only 0.196 million SOLS were installed annually against the 1.4 million as stated above.

JNSM marked a shift in its approach to the promotion of SOLS from strictly State backed to market driven commoditisation of SOLS through innovative and sustainable business models [24]. Accordingly, Solar Photovoltaic Programme was aborted and instead “The capital subsidy – cum – refinance scheme for installation of solar off-grid (photovoltaic and thermal) and decentralised applications” is introduced. In order to reduce per unit cost and expand the SE applications market, financial institutions[9] (FIs) are roped into providing financial assistance through capital subsidy and interest subsidies. The models of the SE applications and the suppliers are prior enlisted by the ministry and the FIs are expected to publicise, promote, finance and monitor these technologies. However, the pattern in which the costs of the systems are fixed and the subsidies are designed, do not appear to be of a notable financial support to the cliental group that opt to procure small units ($10W_p$–$40\,W_p$) (For detailed economic analysis see [25]). Under this scheme the banks are allowed to “release the capital subsidy to the supplier (on behalf of the borrower) only after satisfactory installation and commissioning of the system”. Given that this scheme, assigns no role to the local nodal agencies or any independent validation and testing body, the banks are left to attest for efficiency of installation of the systems. With banks' limited knowledge about the nuances of the technology and the absence of an independent testing body, once the funds are released to the supplier, the consumers are left high and dry in case of anomalies in the installation of the system. Though commercialising REs is one of the crucial steps towards efficient diffusion and long term sustenance of the technology [26], considering the cliental group, the status of the technology and nature of the market, treading this path warrants caution.

The State also designed schemes to promote SOLS in remote villages through the Remote Village Electrification Programme.[10] This is a centrally sponsored subsidy driven programme implemented by local agencies. While the central government is incurring 90% of the cost for installation of all other renewable electricity generation systems,[11] installation of SOLS received a subsidy of only 30% of its cost contrary to 50% financial assistance[12] provided under the Solar Photovoltaic Programme that was terminated. Given that photovoltaic systems are costly, SOLS with minimum capacity of one (or two) light points costs Rs 6000 (Rs 10,000), and investing 70% of the cost i.e. Rs 4200 (Rs 7000) at a time would prove burdensome for a poor household. Further, due to the procedural complexities involved, procuring loans from banks would be cumbersome which would discourage the potential user and also hesitance on the part of banks to aid these households which seldom possess assets worth mortgaging. Even though, the scheme prescribes the state to pool finances for half of the remaining cost of the systems, this would be highly determined by availability of the finances, priorities of the state, political considerations and so on which would in turn make it difficult for the implementing agencies to cater to all unelectrified households. A critical look into the policies reveals that policy attention towards SE, albeit after a long time, is less favourable to off-grid SE applications. Further, loosely framed policies might slower the process or even turn out to be counterproductive.

## 3. Off-grid solar lighting systems: an overview

### 3.1. Diffusion of SOLS: trends and patterns

The two most widely used SOLS in India are SLs and SHs. While SL is a portable lighting system with only one lighting point, SH is a fixed system with at least two lighting points, fans and even television (the nature and number of appliances that can be operated depends on the capacity of the system). Fig. 1 presents the cumulative installation of SOLS in India over the past sixteen

[8] Unlike the other SE applications in the programme, no phase wise targets were set for SOLS.

[9] Commercial Banks and Regional Rural Banks eligible for drawing refinance from National Bank for Agriculture and Rural Development.

[10] The objective of the programme is to provide basic lighting facilities through REs in those unelectrified remote census villages, unelectrified hamlets of electrified census villages where grid connectivity is either not feasible or not cost effective and not covered under Rajiv Gandhi Village Electrification Scheme and electrified villages/hamlets where power availability is less than six hours per day averaged over the year. The scheme came into effect from financial year 2012–2013.

[11] Biomass, hydro, mini or micro grid solar energy are the REs considered under this programme.

[12] 50% for normal areas and 90% for remote and far flung areas.

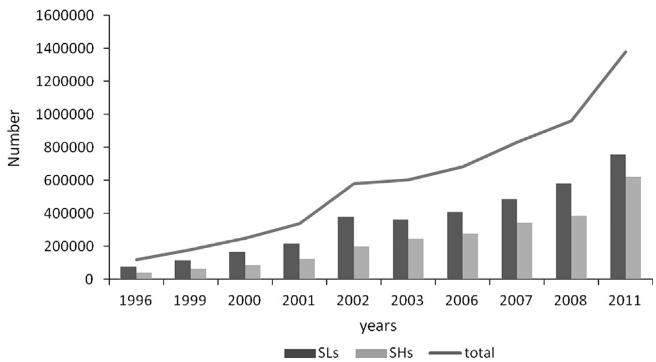


**Fig. 1.** Cumulative Installation of Off-Grid Solar Photovoltaic Lighting Systems.
*Source*: Compiled from Annual Reports of MNRE.

years.[13] According to the latest MNRE estimates 1.376 million SOLS had been installed throughout the country – 0.756 million SLs and 0.62 million SHs. It is evident that over the years SLs are relatively well disbursed compared to SHs. However, SHs are catching up with SLs.

Following the trend observed in Fig. 1, we divided the period to observe the growth of the SOLS as a whole and the relative growth of the two systems – SLs and SHs. The results are presented in Table 1.

In the past sixteen years the sale/installation of SOLS has been growing at a rate of 16.4% per year. SHs are growing at a faster pace compared to SLs. The total growth rate exhibited a decline over time by dropping from 15.6% during 1996–2000 to 12% in early 2000s and to 10.6% in the last 5 years. The growth in SLs declined sharper than that of the SHs and thus widening the gap between the growth rates. In the last 5 years, almost a five percent difference in the growth rates of the two applications has been recorded. This indicates selective efforts of the State in promotion of the technologies and increasing acceptance of SHs in the economical and technological front. Table 2 exhibits states' performance in promoting and selling/installing SOLS. Punjab, Karnataka and Tamil Nadu top the chart in the growth of sales of SLs, whereas Haryana, Bihar and Tamil Nadu surpass other Indian states with respect to SHs. The relative performance of the states in promoting the two technologies is statistically[14] comparable.

However, in a given state, the growth (in sale/installation) of the two technologies varies significantly. For more than 50% of the states, the difference in the growth rates (of SLs and SHs) is above ten percent. Further, the variation across the states in installing SHs is two times higher than the variation among states in sale of SLs.[15] Thus, we can conclude that while only a few states are performing exceptionally well with respect to SHs, performance of the states regarding SLs is relatively even.

Table 3 shows states' share of SLs and SHs. More than half of the SLs had been installed in four states namely Uttar Pradesh, Haryana, Maharashtra and Bihar and three-fourth of SHs are installed in four states namely Uttar Pradesh, West Bengal, Rajasthan and Haryana. On examining the installation/sale pattern across states, one can conclude that there are high variations in installation of SHs and comparatively lower variations in installation of SLs indicating that SLs are relatively evenly installed across the states.

However, Fig. 2 depicts that, variations in general and specifically that of SH installations has steadily come down over the years and thus it is encouraging to note that that SHs are increasingly finding place across India.

[13] Though Solar Photovoltaic demonstration programme is been implemented since late 1980s, data is available only from the year 1996.

[14] Spearmann rank correlation is 0.44, statistically significant at 10%.

[15] The coefficient of variation of the growth rates of SLs and SHs across the states is 30.54 and 61.50, respectively.

**Table 1**
Growth rates of the two Off-Grid Solar Lighting (in percentage).
*Source*: Compiled from Annual Reports of MNRE.

| Year | Solar Lanterns | Solar Home Lighting | Total |
|---|---|---|---|
| 1996–2000 | 15.62 | 15.79 | 15.68 |
| 2001–2006 | 11.26 | 14.38 | 12.44 |
| 2007–2011 | 9.23 | 12.51 | 10.64 |
| **1996–2011** | **15.16** | **18.31** | **16.41** |

**Table 2**
Growth Rates of Off-Grid Solar Lighting Systems Across States (1996–2011).
*Source*: Compiled from Annual Reports of MNRE.

| Ranks | States | Growth Rate (SLs) | States | Growth Rate (SHs) |
|---|---|---|---|---|
| 1 | Punjab | 22.48 | Haryana | 73.50 |
| 2 | Karnataka | 22.11 | Bihar | 58.75 |
| 3 | Tamil Nadu | 20.17 | Tamil Nadu | 36.82 |
| 4 | Maharashtra | 19.85 | Karnataka | 36.61 |
| 5 | Haryana | 18.31 | Madhya Pradesh | 34.30 |
| 6 | Bihar | 16.47 | West Bengal | 33.05 |
| 7 | Jammu & Kashmir | 15.99 | Rajasthan | 26.59 |
| 8 | Madhya Pradesh | 14.60 | Kerala | 24.54 |
| 9 | Gujarat | 14.42 | Gujarat | 22.05 |
| 10 | West Bengal | 14.23 | Odisha | 20.62 |
| 11 | Rajasthan | 12.44 | Jammu & Kashmir | 19.98 |
| 12 | Andhra Pradesh | 12.31 | Himachal Pradesh | 19.81 |
| 13 | Odisha | 11.25 | Maharashtra | 19.47 |
| 14 | Uttar Pradesh | 10.30 | Punjab | 15.01 |
| 15 | Kerala | 9.38 | Assam | 14.30 |
| 16 | Assam | 9.16 | Uttar Pradesh | 10.59 |
| 17 | Himachal Pradesh | 8.60 | Andhra Pradesh | 6.31 |
| | Others (NGOs/ PSUs) | 16.90 | Others (NGOs/ PSUs) | 16.31 |
| **India** | | **15.16** | **India** | **18.31** |

*Note*: NGOs: Non-Government Organisation and PSU: Public Sector Units.

### 3.2. Central financial assistance

In order to promote and demonstrate SOLS, MNRE provides Central Financial Assistance (CFA) to the states. This is also extended to the manufacturer's association, NGOs, establishment and operation of *Akshaya Urja* (AU) shops[16] and research and development activities of solar photovoltaic technology. Table 4 exhibits the states' average share of CFA for the years from 1997–98 to 2011–12. On an average five states – Uttar Pradesh, West Bengal, Rajasthan and Jammu and Kashmir receive more than fifty percentage of the CFA. Further, the share of the funds the states receive has largely remained the same over the years.[17]

A simple exercise is conducted to examine the correlation between disbursement of CFA and energy poverty intensity faced by the state. Fig. 3 depicts a two way scatter plot of

[16] Show room-cum-sales- and service centers of off-grid solar applications owned by the government or private parties. These were earlier referred to as *Aditya* solar shops.

[17] We calculated rank correlation of the states with respect to their share of CFA over the years. For most of the years we got statistically significant positive rank correlation indicating that the position of the states with respect to their share of CFA has remained the same for most of the years.

**Table 3**
States' share of installation of Off-Grid Solar Lighting Systems 1996–2011.
*Source*: Various Annual Reports of MNRE.

| Ranks | States | SLs share | States | SHs share |
|---|---|---|---|---|
| 1 | Uttar Pradesh | 22.85 | Uttar Pradesh | 30.33 |
| 2 | Haryana | 12.46 | West Bengal | 21.06 |
| 3 | Maharashtra | 11.58 | Rajasthan | 14.48 |
| 4 | Bihar | 11.21 | Haryana | 6.89 |
| 5 | Kerala | 6.94 | Kerala | 5.51 |
| 6 | Andhra Pradesh | 6.44 | Karnataka | 5.29 |
| 7 | Gujarat | 5.33 | Jammu & Kashmir | 3.30 |
| 8 | Jammu & Kashmir | 4.75 | Himachal Pradesh | 2.87 |
| 9 | Himachal Pradesh | 3.79 | Madhya Pradesh | 1.91 |
| 10 | West Bengal | 2.98 | Bihar | 1.66 |
| 11 | Punjab | 2.95 | Gujarat | 1.53 |
| 12 | Tamil Nadu | 2.84 | Punjab | 1.47 |
| 13 | Madhya Pradesh | 2.01 | Tamil Nadu | 1.28 |
| 14 | Odisha | 1.71 | Assam | 1.01 |
| 15 | Karnataka | 1.24 | Odisha | 0.86 |
| 16 | Rajasthan | 0.80 | Andhra Pradesh | 0.33 |
| 17 | Assam | 0.12 | Maharashtra | 0.21 |
| | **India** | 100 | **India** | 100 |

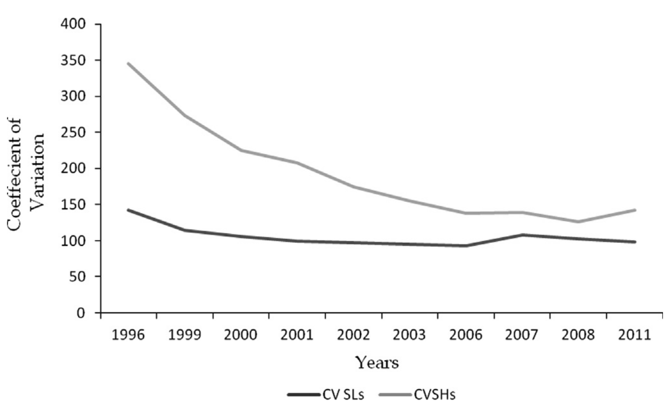


**Fig. 2.** Disparities in the Installation of Off-Grid Solar Systems Across states.
*Source*: Calculated using data provided by various MNRE reports.

energy poverty intensity of the state and states' share of CFA. Not being able to access a modern and clean source of energy for lighting[18] is termed as energy poverty and the ratio of number of households in energy poverty to the total number of households is defined as the energy poverty intensity of the state.[19] Since, the demonstration and promotion of the energy services as infrastructure involves long term planning, and considering only 1 year of financial assistance would be inappropriate. Therefore, we took an average of the state's CFA share for the years 1997–98 to 2004–05. Uttar Pradesh, West Bengal and Rajasthan, where energy poverty intensity is above the national average, received above average share of CFA to promote and demonstrate solar applications (Fig. 3). On the other hand, states like Bihar, Assam and Odisha though suffer from energy poverty intensity way above the national average; CFA share allotted to these states is below the national average.

### 3.3. A household level analysis

In this section we shall examine the diffusion of SOLS among the households in rural India using the data provided by 59th

[18] That is households using fuel-wood, kerosene, dung cake etc.

[19] We used data from the Energy Statistics provided by NSSO, 61st round (2004–05) to arrive at this.

**Table 4**
States' Share of CFA for the Promotion of Solar Power: 1997–98 to 2011–12.
*Source*: Calculated from data provided by the MNRE.

| Rank | States | Average Share (1997–2012) |
|---|---|---|
| 1 | Uttar Pradesh | 22.11 |
| 2 | Rajasthan | 9.97 |
| 3 | West Bengal | 9.84 |
| 4 | Jammu & Kashmir | 8.68 |
| 5 | Madhya Pradesh | 8.36 |
| 6 | Haryana | 5.38 |
| 7 | Punjab | 5.23 |
| 8 | Maharashtra | 4.98 |
| 9 | Himachal Pradesh | 4.86 |
| 10 | Karnataka | 4.30 |
| 11 | Kerala | 3.27 |
| 12 | Gujarat | 2.97 |
| 13 | Andhra Pradesh | 2.54 |
| 14 | Tamil Nadu | 2.03 |
| 15 | Odisha | 1.91 |
| 16 | Bihar | 1.90 |
| 17 | Assam | 1.69 |

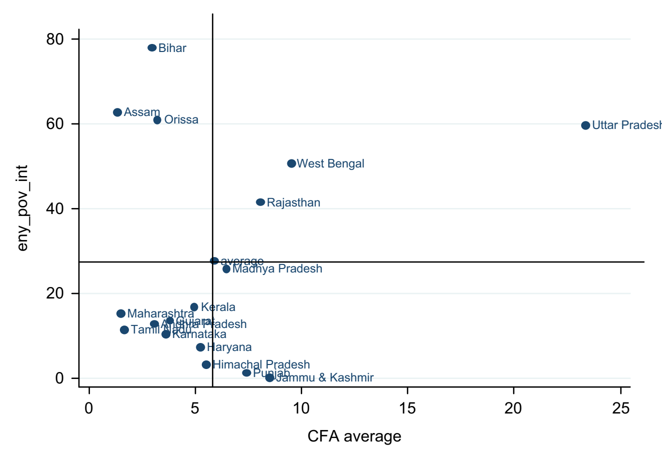


**Fig. 3.** Scatter Plot: CFA Share to promote Off-Grid Solar Lighting Systems to the Share to Intensity of Energy Poverty.
*Source*: Calculated from annual reports of MNRE and NSSO 61st round.

NSSO (2003) on Situation assessment Survey, Access to Modern Technology for Farming.[20]

Table 5 displays the energy usage pattern for lighting among rural households in India. Electricity followed by kerosene is the widely used sources of energy for lighting in rural India. SE is a sparsely opted source of energy with only three of thousand households using it for lighting. Madhya Pradesh stands first with six out of thousand households using SE for lighting followed by Uttar Pradesh, Karnataka and Kerala.

Table 6 showcases SE as an adequate source of energy for lighting among households. Only in eleven states, households reported that they opt for SE as a primary source of energy. As a whole, 53% of the households that adopted SE for lighting use it as the primary source of energy. It is encouraging to note that 68% of these households find it as an adequate source of energy and do not complement their lighting requirements with any other source of energy. Particularly in Rajasthan, Madhya Pradesh

[20] This is the only data set available that gives information on household characteristics of the users of SOLS. Since, the period of survey is nearly eight years old, we fail to take into account the changes that happened since then. This is one of the major drawbacks of the study. Further, since the survey is conducted among the farmer households, we are limited to examine the adoption of SOLS among the farmer's households. However, as farmer's households constitute about 80 percent of the total rural households and thus we can generalize the results to rural India as a whole.

**Table 5**
Diffusion of Solar Energy for Lighting (Per Thousand Households).
*Source*: Calculated using NSSO 59th Round.

| State | *Other Energy Source for Lighting* | | | Solar |
|---|---|---|---|---|
| | Electricity | Kerosene | Others | |
| Madhya Pradesh | 641.72 | 294.84 | 61.87 | 5.56 |
| Uttar Pradesh | 213.93 | 671.36 | 111.91 | 4.97 |
| Karnataka | 771.98 | 77.87 | 146.06 | 4.70 |
| Kerela | 740.73 | 125.09 | 131.88 | 3.48 |
| Himachal Pradesh | 936.56 | 14.68 | 48.76 | 2.81 |
| West Bengal | 299.21 | 637.33 | 59.89 | 2.57 |
| Bihar | 143.59 | 827.09 | 28.05 | 2.11 |
| Odisha | 207.43 | 753.03 | 38.62 | 1.99 |
| Haryana | 839.41 | 110.92 | 49.68 | 1.97 |
| Assam | 214.88 | 504 | 281.12 | 1.72 |
| Rajasthan | 454.1 | 528.26 | 16.55 | 1.37 |
| Maharashtra | 803.77 | 180.7 | 15.53 | 0.11 |
| Jammu & Kashmir | 914.3 | 54.64 | 31.06 | 0.06 |
| Andhra Pradesh | 626.78 | 121.39 | 251.83 | 0.05 |
| Tamil Nadu | 867.61 | 118.33 | 14.06 | 0.04 |
| Gujarat | 804.31 | 180.59 | 15.1 | 0.00 |
| Punjab | 942.45 | 30.94 | 26.61 | 0.00 |
| **India** | **480.05** | **438.34** | **78.965** | **2.64** |

*Note*: Others primarily include dung cake and firewood.

**Table 6**
Off-Grid Solar Lighting Systems: Preference and Adequacy.
*Source*: Calculated using NSSO 59th Round.

| States | Solar all per 000′ households | *Preference of solar energy and its adequacy* | |
|---|---|---|---|
| | | Solar as primary energy source (%) | Solar Energy Adequacy (%) |
| Madhya Pradesh | 5.56 | 28.40 | 100.00 |
| Uttar Pradesh | 4.97 | 56.34 | 76.68 |
| Karnataka | 4.70 | 87.09 | 77.08 |
| Kerala | 3.48 | 37.41 | 100.00 |
| Himachal Pradesh | 2.81 | 0.00 | 0.00 |
| West Bengal | 2.57 | 100.00 | 11.33 |
| Bihar | 2.11 | 60.43 | 41.52 |
| Odisha | 1.99 | 46.34 | 61.51 |
| Haryana | 1.97 | 0.00 | 0.00 |
| Assam | 1.72 | 0.00 | 0.00 |
| Rajasthan | 1.37 | 79.77 | 100.00 |
| Maharashtra | 0.11 | 0.00 | 0.00 |
| Jammu & Kashmir | 0.06 | 0.00 | 0.00 |
| Andhra Pradesh | 0.05 | 0.00 | 0.00 |
| Tamil Nadu | 0.04 | 0.00 | 0.00 |
| Gujarat | 0.00 | 0.00 | 0.00 |
| Punjab | 0.00 | 0.00 | 0.00 |
| **India** | **2.64** | **53.37** | **67.65** |

and Kerala all the households that opt for SE as the primary source of energy for lighting find it adequate. On the other hand, in states of West Bengal and Bihar a substantial percentage of SOLS adopters find it inadequate.

At a macro perspective, despite increasing attention towards development, promotion and usage of the SE at large, why did installation of SOLS exhibited a declining trend in the recent past? Is it because SE technology trajectory in India reached a juncture where tail end solar applications like SOLS are slowly being supplanted by grid connected SE? If that is the case, is this transformation spontaneous or synthesized? What are the factors that determine this transformation and is this transformation warranted taking into account India's energy scenario – production, distribution and usage in general; sustenance of SE and its amalgamation into India's energy plan. At a micro level, what are the reasons behind the relatively even distribution of SLs compared to SHs? What determines the increasingly even installation of SHs in the recent past? What is the reason behind energy poor states like Odisha, Assam and Bihar to be absent in the priority list in CFA disbursement? As 44% of rural households using kerosene for lighting are the possible cliental group of SOLS, it is important to analyse what works. Why in few states majority of the SE users use it as primary source of energy and find it adequate while it is contrary in others? Has it got to do with the state's efficient mechanism in financing, sale/installation and after sales services or the grim scenario of alternative sources of energy? Throwing open these issues into the academic domain, we believe that they would add to the discourse on sustainable development.

## 4. Factors determining the adoption of off-grid solar lighting systems: a household level analysis

The above observed trend is a result of adoption choices made at a disaggregated level i.e. at household level. Therefore, it is worthwhile to examine the factors that determine the choices made at household level. Success of the programme largely depends on the implementation of the programme which lies within the states' purview i.e. state level policies, agencies involved, steps taken by the state to develop and implement the programme and state level socio-economic conditions. The present econometric exercise adopts a heuristic framework based on the survey of literature on rural energy, diffusion of rural energy technologies in developing countries, identifies certain hypotheses and zeroes down on a host of household and state level characteristics. We consider that the household faces three choices – to adopt SOLS as a sole source of energy for lighting or to complement SOLS with other sources of energy or not opt for SOLS at all. We employ a multinomial logit model to examine the factors that determine the households' choice.

### *4.1. Hypothesis and variable construction*

#### *4.1.1. Market and infrastructure/supply factors*

Rural energy technologies (RETs) need to be considered beyond the conventional technologies for two reasons. Firstly, the innovation of RETs is directly or indirectly related to non-market components and thus non-market interactions play a primary role. Secondly, the target group of these technologies is characterised by limited purchasing power and thus need for innovation would hardly be influenced by the demand from the users (For example see [27,28]). Brown (1981) envisages that market and infrastructure perspective takes the stance that the opportunity to adopt a particular technology is essentially dependent on various supply side factors which primarily involves nature and operation of the diffusion agents [29]. Literature recognised different possible interventions and various combinations of public and private partnership in successful diffusion of RETs [30]. Litchman (1987) stressed on the importance of striking a balance between 'investing in people' and 'production investment' [31] or in words of Reddy (2002), synthesis of 'hardware' and 'software' [10]. The preparedness of the rural economy to absorb and use the technology largely

depends on investing on people i.e. building close network of the local bodies that understand the local conditions better. Following variables indicate supply factors.

*4.1.1.1. Central funds to the states.* Since CFA is granted to the state, as mentioned earlier, to promote and demonstrate SOLS, we take share of CFA to states as a proxy to market and infrastructure component. This data about the financial assistance yearly is provided by MNRE. We hypothesise that with every one unit increase in the CFA share to the state increases the probability of the household belonging to that state to opt for SOLS increases.

*4.1.1.2. Akshaya Urja shops.* The Ministry has been promoting the establishment of AU shops in major cities of the country since 1995 with a view of easy availability of SE and outlets for after-sales services. By 2003, in line with the time period of the data we are using, there are 29 AU outlets throughout the country. The ratio of the AU shops to every one million households shall give us the indication of the presence of the facilitators. We hypothesise that with every one unit increase in the ratio, the probability of the household to opt for SOLS will increase.

*4.1.2. Household-specific factors*

One of the few characteristics that clearly distinguish successful and unsuccessful innovation is whether the technology meets the needs of the particular users [32]. In industrialised countries or modern sectors of the developing countries, indicators of users' needs are frequently sought through observation of people's behaviour towards similar products, through specific market surveys or through the signals provided by the market or price mechanism. This stands different from the RETs where no explicit demand signals are provided [33]. Therefore we consider range of economic, social, locational and demographic factors that implicitly indicate adoption choice of the household.

*4.1.2.1. Status of solar off-grid lighting systems.* Status of the systems i.e. extent of the usage and adequacy of the energy service acts as a demonstration effect and influences adversely/favourably the adoption of the technology.

*4.1.2.1.1. Extent of the usage and adequacy of the system together determine the status of the systems.* The adoption of a technology basically depends upon learning and communication process. The process involves a variety of stages – awareness, interest, evaluation, trial, and adoption [34]. Communication process is effective with larger number of households depending on SOLS. This will result in better dissemination of information which will in turn act as a demonstration effect and encourage the households to opt for SOLS. Further, it will help the household to assess the pros and cons of installing the plant, learn from each other and lessen the operation cost of the facilitating agencies and thus bring about active participation of the agent as well. To take this factor into consideration, we take the share of households using SOLS per every thousand households in the state.

*4.1.2.1.2. Adequacy.* Usage of SOLS as primary source of energy largely depends on the quality of the product, after sales and technical support, awareness of the costumer about its usage, and climatic conditions. Cumbersome in operation, unfavourable climatic conditions, absence of minimum trouble-shooting know-how among the users, inefficient after sales and technical support might lessen the user's confidence about the technology and its ability to meet their requirements.. To take this into account, we take the percentage of households that perceived SE to be an adequate source of energy for lighting. Combining the above two indicators i.e. extent of usage and adequacy of the system, we created a status index of SOLS.[21] The higher the value of the index the better the status of SOLS in any given state.

*4.1.2.2. Cost of the system.* A few selected SOLS models that had been specified by the MNRE met different load requirements and thus vary in costs.[22] However, all the beneficiaries receive an equal amount of subsidies over the purchase of the system. Therefore, all the households face similar investment costs. Thus, in order to incorporate cost factor into the analysis, we take the financial strength of the house hold i.e. annual income of the household as a proxy for the ability of the household to purchase SOLS.

*4.1.2.3. Status of alternative sources of energy.* The availability, adequacy and cost of alternative sources of energy have an impact on the households' choice of adopting SOLS. In this regard we take two most important alternative sources of lighting – electricity and kerosene.

*4.1.2.3.1. Availability.* Usage of electricity as a primary source of energy depends on efficient distribution mechanism i.e. well laid electricity network. To take this into consideration, we consider the presence of households that depend on electricity as their primary source of lighting i.e. the share of households using electricity as their primary source of energy per every thousand households in the state. We hypothesize that efficient distribution mechanism will adversely influence the household's choice to adopt SOLS.

*4.1.2.3.2. Adequacy.* Apart from a well laid network, adequacy of electricity also determines the adoption of the energy service under question. Percentage of households that reported to find it as an adequate source of energy gives a proxy for the adequacy of the electricity as a primary source of energy for lighting in a given state. Combining the above two indicators, a status index has been calculated. Higher the index value the better is the status of the source of energy and we hypothesise that the probability to adopt SOLS will fall with betterment in the status of the alternative source of energy. A similar exercise has been conducted for kerosene.

*4.1.2.4. Cost of alternative source of energy.* Since NSSO 59th round do not provide information on the cost of fuel consumption at household level, we used information provided by NSSO 61st round on energy consumption at household level.[23] We calculated the average per capita expenditure incurred on lighting i.e. expenditure an individual has to incur if he/she resides in a household that exclusively depends on electricity for lighting. Using this we arrived at the proportion of the lighting fuel expenditure a household incurs to the total monthly per-capita expenditure. Similar exercise is being conducted for kerosene.

Since power supply, laying of electricity network, availability and cost of kerosene (PDS and non-PDS system), and solar illumination widely varies even in a given state, the analysis is

[21] In order to capture the status of energy we considered the extent of the use of energy and the adequacy of the energy. Values are assigned to each of these components. Zero value is assigned to non usage of SE, one if the household is using SOLS but finds it inadequate, and value 2 if the household uses SOLS and finds it adequate. Index is calculated as follows. Status of energy $=0[\{(\text{Number of households not using SOLS})/\text{Total number of households}\}\times 1000]+1[\{(\text{Number of households who find SOLS inadequate})/\text{Total number of households}\}\times 1000]+2[\{(\text{Number of households who find SOLS adequate})/\text{Total number of households}\}\times 1000]$.

[22] See appendix for the details on load requirements and cost of the systems.

[23] The survey period of 59th period is January–December, 2003 where as survey period of NSSO 61st round is 2004–05. Since the survey periods are consecutive, we assume no drastic differences in the prices of the fuel. Thus we use the information provided by 61st round for data of 59th round.

**Table 7**
Maximum Likelihood Estimates Of The Multinomial Logit Model For Adoption Of Solar Lighting Systems At Household Level.

| Regressors | Choice 1 (only solar) Odds | Choice 2(solar and alternative energy) Odds |
|---|---|---|
| CFA_share | 0.963 (−0.09) | 1.027 (0.12) |
| AU | 1.000 (0.62) | 0.999 (−1.55) |
| Sol_status | 3.210[a] (4.74) | 2.894[a] (7.14) |
| Ele_cond | 1.834 (0.496) | 0.476[b] (−1.64) |
| Ker_cond | 2.973 (0.73) | 0.378 (−1.24) |
| Financial_strength | 0.945 (−0.12) | 2.694[a] (3.29) |
| edu | 1.108 (0.26) | 1.078 (0.29) |
| Sol_scope | 1.060 (0.56) | 1.078 (0.29) |
| Spl_grp | 1.141 (0.35) | 0.923 (−0.30) |
| Ele_cost | 0.899 (−0.47) | 1.066 (0.56) |
| Ker_cost | 1.024 (0.04) | 0.372[a] (−2.74) |
| Log Likelihood | −738.414 | |
| LR $\chi^2_{(22)}$ | 193.06 | |
| Number of observations | 46,502 | |

Figures in parenthesis are $Z$ values.

[a] Statistically significant at 5%.

[b] Statistically significant at 10%.

conducted at the most disaggregated geographical level as possible by taking into consideration state 'region' instead of state.

*4.1.2.5. Scope of solar system.* Owing to the fact that a basic SOLS is equipped with only one or two lighting points and given the high cost of the system, a wider lighting requirement might discourage a household to exclusively depend on SE and thus push them to complement with alternative source of energy. To test this hypothesis we take the size of the household as a proxy for requirement of illumination.

*4.1.2.6. Education.* RET studies emphasize the need for participation of the end users in the successful diffusion of technologies (For example see [35]). The two major reasons are that firstly, participation becomes far more important in public sector activity where complex objectives are pursued. For instance trying to reach people who are too poor to reach the market and absence of inbuilt procedure to ensure that the clients are being attended to [36]. Secondly, for efficient and continuous usage of the system it is important that the user have adequate know-how about the operation of the device; to follow the instructions and to give feedback to the implementing agencies. Studies argue that unpreparedness of the users to handle the technology will eventually lead to abandoning them. Therefore, we take the educational status of the user household as a proxy for their ability to participate in this process. NSSO classifies the education status of the household into eleven categories. For the present analysis we clubbed these eleven categories into two broad categories – no-formal education and formal education.

*4.1.2.7. Special category.* Through the Solar Lantern Programme and Solar Photovoltaic Programme, the State was promoting usage of SOLS among less developed societal groups – Scheduled Cast (SC) and Scheduled Tribe (ST) communities. Thus we examine if the household belonging to this community have any better odds to adopt SOLS.

## 4.2. Adoption of off-grid solar lighting systems: a multinomial logit model

Multinomial logit model can be motivated by a random utility formulation. Let $U^*$ be the maximum attainable utility the household gets by adopting different choices of energy. $U^*ij$ as the realized utility that a household $i$ gets by choosing particular choice j. Suppose, stochastic utility of $i$th household faced with $J\,(=1, 2...j, j+1,..., m)$ choices is

$$U^*ij=\beta_j^{'}.X_i+\varepsilon_{ij}\ \ldots \tag{1}$$

where, $X_i$ is the vector of non-stochastic components and $\varepsilon_{ij}$ is the stochastic component. $X_i$ in our model denotes the vector of the household, state and state-region level characteristics. If the household makes choice $j$ in particular, then we assume that $U^*ij$ is the maximum among the $J$ pay-offs. Hence, the statistical model is driven by the probability that choice $j$ is made, such that $P_{ij}$=Prob $(U^*ij > U^*ik)$ for all other $k \neq$. Our interest is to predict the probability $P_{ij}$. We assume that the logit $L$ is a linear explanation of explanatory variables:

$$L_i=\beta_j^{'}.X_i\ldots \tag{2}$$

Expanding Eq. 2, the model constructed for our purpose is

$$\begin{aligned}L_{ijk}=\alpha&+\beta_1\ \ln CFA_{ik}+\beta_2 AU_{ik}+\beta_3\ \ln sol\_status_{ijk}\\&+\beta_4\ \ln fin\_str_{ijk}+\beta_5\ \ln ele\_status_{ijk}\\&+\beta_6\ \ln ele\_\ \cos\ t_{ijk}+\beta_7\ \ln \mathrm{ker}\_status_{ijk}\\&+\beta_8\ \ln \mathrm{ker}\_\ \cos\ t_{ijk}+\beta_9\ sol\_sco_{ijk}\\&+\beta_{10}\ edu_{ijk}+\beta_{11} spl\_grp_{ijk}+u_{ijk}\ldots\end{aligned} \tag{3}$$

for all $i=1,2,\ldots,n_1$, $j=1,2,\ldots,n_2$ and $k=1,2,\ldots n_3$ where $n_1 > n_2 > n_3$.

$i$, $j$ and $k$ are indexes of household, state region and state respectively and $u_{ijk}$ is the error term

lnCFA: log of state's share of Central Funds to state
AU: Presence of *Akshaya Urja* Outlets
lnSol_status: log value of Status of SOLS in a given state
lnFin_str: log value of financial strength of the household
lnEle_status: log value of Status of Electricity
lnEle_cost: log value of Cost of electricity
lnKer_status: log value of Status of Kerosene
lnker_cost: log value of Cost of kerosene
sol_sco: scope of solar (size of the household)
edu: educational status. Dummy variable which takes value one if at least one adult in the household receives formal education and zero if not.
spl_grp: special category. Dummy variable which takes value one if the household belongs to SC/ST community and zero if not.

## 4.3. Data and the method

Present econometric exercise is based on the survey on Situation Assessment Survey, Access to Modern Technology for Farming i.e. 59th NSSO (January–December, 2003). The data comprises of 20 states, 62 state regions with 46,502 households and our unit of observation is households. The data set has been edited based on the household, state and state region level characteristics. We used the SPSS 15.0 and STATA 10.0 statistical package for our analysis and estimation.

## 4.4. Results and discussion

Table 7 presents the likelihood estimates of the model. The estimates indicate that CFA share of the states do not have any significant impact on household's choice of opting for solar. This result points out that a linear mode of development plan, i.e. the higher the funds the better is the diffusion, need not necessarily hold good for rural energy technologies like SOLS. Presence of AU shops, showed no significant impact on household's choice of opting for SOLS. One should note that by 2003, it had been only

eight years since the programme has been promoted and in the majority of the states there is only one AU outlet primarily located in urban areas.[24] Betterment in the status of SOLS enhances the household's probability to opt for the same. One unit increase in the status of SOLS enhances the household's odds to use SOLS as the only source of energy by more than 200% and complement it with an alternative source of energy by more than 100%.

Financial strength of the household proved to have significant impact on household's choice of using SOLS as a complementary source of energy. If the financial strength of the household improves by one unit, it enhances the household's odds to use SOLS as complementary source of lighting by 1.7 times. Owing to the fact that more than 50% of the households fall under the low income class, it is an issue of concern that the financial strength of the household determines household's choice of opting SOLS. Status and cost of alternative sources of energy proved to have no impact on the household's decision to choose SOLS only. However, the status and cost of alternative sources of energy have a significant impact on household's choice to use it as a complementary source of energy. With every one unit improvement in the electricity status of the state, household's choice to use SOLS as a complementary source of energy reduces by 53%. Increase in the cost of kerosene discourages the households' choice to use SOLS as a complementary source of energy. With every one unit increase in the cost of kerosene, the odds of the household to use SOLS as a complementary source of energy reduce by 63%. With limited financial resources at hand, increasing cost of an inefficient but easily available (relatively) source of energy like kerosene might put-off the household's choice of investing on any other source of energy. Particularly, limited confidence on SOLS, due to imperfect knowledge about it, discourages the households to part with their minimal resources to invest on one. This is where lies the role of the State to educate the users about the technology-cost-benefit analysis of SOLS over kerosene, social and health benefits accrued, financial support extended by the State, ease of operation and availability of after installation services.

Education status of the household proved to have no impact on household's choice of SOLS. This indicates that the nature of technology is such that its operation and minimal trouble shooting mechanism does not demand a formal education level. Given the poor education status of the farmers' households where 47% of the households do not have at least one formally educated adult in the family, no influence of education on adoption choice is hopeful. Contrary to the hypothesis, increase in the illumination requirement of the household does not discourage the household's choice to opt SOLS only. The average size of the household that depends exclusive on SOLS is same as that of any average household size i.e. six. This leads us to maintain that, SOLS are efficient enough to provide illumination for a larger household. If a household belong to the SC/ST group it do not have any better odds to opt for SOLS. One should note that, according to the clause laid in the Solar Lantern Programme and Solar Photovoltaic Programme, state nodal agencies were directed to allocate 15% and 10% of the targets to SC and ST beneficiaries, respectively. This indicates that, though this is largely State driven programme and characteristics of the beneficiaries are pre-determined this need not necessarily ensure adoption of the technology.

## 5. Summary and agenda for future work

Present study makes a case for one of the tail end SE applications-solar off-grid lighting systems (SOLS) which has a potential to address a long standing issue of energy poverty in the rural India. Though the energy (for lighting) status of rural India indicates a potential for SOLS, degree of efforts to promote the technology do not match its potential. While the overall installation of SOLS witnessed a decline, solar home lighting systems, which are technologically advanced, exhibited an encouraging trend. Variations in the performance of the states with respect to the two SOLS are observed. Central financial assistance to the states is non-comparable to the energy poverty intensity of the states. Compared to other sources of energy, solar is sparsely opted. More than half of the SOLS adopters use it is a primary source of lighting and on an average more than 60% of them found it adequate. It is encouraging to note that more than 50% of the households that adopt SOLS belong to low-income class.

CFA share to states has no significant impact on household's choice to adopt SOLS. Improvement in the status of SOLS in a given state encourages households to opt SE. Financial strength of the household has a significant and positive impact on the household's choice to use SOLS as a complementary source of energy. Better status of electricity and increasing cost of kerosene has a negative impact on households' choice to adopt solar systems as a complementary source of energy. Owing to the fact that education levels of the farmer households in rural India are poor, it is encouraging to note that adoption of SOLS is not influenced by the education status of the household. It is also hopeful to learn that scope of SOLS is not confined to small family size.

Solar energy has been lately exalted and it is envisaged to aid the Indian economy to the path of sustainable development. While solar energy escalates these new heights, it is worthwhile to take stock of more than two decades of efforts in promoting SOLS and the prospects it holds. We believe that the present paper partially succeeded in doing the same. However, a detailed analysis of status of SOLS encompassing the State, manufacturers, facilitators and users; formal and informal institutions that guide the interplay between them is imperative. This analysis ought to be conducted at the most disaggregated level backed by up to date statistics. This, we believe, will bring forth the state of affairs of the sector, promulgate frailties and rise debate for solutions. Owing to its potential in mitigating rural energy poverty, development and promotion of SOLS is one of the ways to align two of India's development goals – inclusiveness and sustainability.

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## Appendix-A

*Cost*: The cost of an SHS depends on the load to be supported, the capacity of the PV modules used to meet the load requirement,

**Table A1**
Specifications and Cost of Solar Home Systems Specified by MNRE under Solar Photovoltaic Programme-2003–04.
*Source*: MNRE booklet on Solar Energy.

| Model | Specifications | Cost |
|---|---|---|
| Model I | one 9 W CFL | Rs 6000 |
| Model II | two 9 W CFLs | Rs 10000 |
| Model III | one 9 W CFL and one fan | Rs 11,000 |
| Model IV | two 9 W CFLs and a fan/TV | Rs 18,500 |
| Model V | four 9 W CFLs | Rs 17,500 |

[24] According to the recent estimates there are 104 AU outlets throughout the country.

and the capacity of the battery to meet the required autonomy. The indicative costs of five different SHS models are listed below.

See Appendix Table A1.

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